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Utilisation of Multi-Robot Team in Completing Tasks Efficiently Than A Robot or A Person Working Alone in Areas as Diverse as Search and Rescue, Aerial Surveillance and Data Gathering

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Abstract

The research article revolves around prioritising multiple-robot teams over a single robot for searching, rescuing, data gathering and other relevant purposes. The issues with managing multiple robots are being evaluated where it can be stated that multiple robots require multiple functions for its operations in a dynamic environment and also comprehensive support. The findings illustrate that aerial robots can function within 390 and 490 seconds therefore, the efficacy for rescuing victims has been more for multiple aerial robots rather than a single robot and a person. The energy of multiple robots has been more during SAR operations than increasing dependency on a single robot and individual.

Keywords

multiple robots, multi-robot, SAR, UAV, victims and others.

INTRODUCTION

The multi-robot system raises certain research challenges where it is a software that always enables effective teamwork. In such a scenario, there is a requirement of comprehensive support is required for designing such interaction, decision-making and also coordination for exploiting the potential of such multi-robot teams. Some rescue organisations have been seen to come together to search and rescue (SAR) several victims therefore, in such conditions, there is a need for development of the communication channels among the robots that are similar to human force [1]. However, the functionalities of the multiple-robot teams are witnessed in a dynamic and error-prone environment where there is again a dire requirement of support for task allocation and decision-making to determine which robot will perform which task and when among the autonomous robots.

The use of a multiple robot is not much threatening in comparison with use of single robots where it has been reported as per the reports of "International Federation of Robotics", there are around 3.5 million robots that have been installed that accounts to be more than the population in the US [2]. It is for industrial purposes, only multiple robots will be beneficial where Boston Robotics, considered to be the leaders within the "space of robots" owns around 80% of Hyundai [2]. There is a team of two robots namely Stretch and Spot, and these robots are involved in the function of stretching its arms for picking up 50-pound boxes and at the same time, dance to the songs when available in their free time.

This article aims to emphasise the role of multiple robots for task completion in diverse tasks such as aerial surveillance, data gathering and others. The multiple teams of employees in the industries are getting replaced by multiple robots and therefore, the robots are taking away the jobs of the employees. UR10 is assumed to be a coworking robot that cost around $25,000 and this robot has already replaced the workers in the factory on the shop floors as seen in some of the retail giants that include Amazon, and Walmart. According to the reports from "World Economic Forum", it has been found that by 2025, 85 million jobs will be lost because of robots [2]. This huge opportunity for job creation for robots instead of employees indicates the creation of multiple teams of employees in different organisational activities.

LITERATURE REVIEW

Multiple Robots and a robot

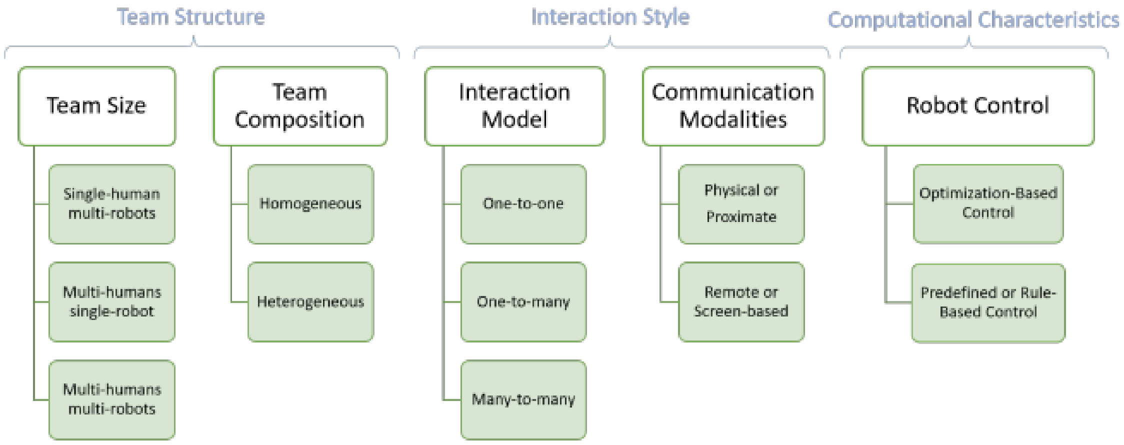


Figure 1: Human-Robot Interactions (HRI)
(Source: [3])

A robot is considered to be a programmable machine that possesses the capability to conduct complex actions. However, an autonomous robot possesses a perception through which it can perceive an environment with the help of sensors, evaluate the reasons for the gained information and eventually delve into making decisions and acting on the environment with the help of actuators without human intervention. [3] opined that there is a single human who has been seen to be interacting with multiple robots due to the task. There are some (semi)autonomous robots in need of intermittent interventions from a specific human operator and supervisor. The performance of the multiple robots has been enhanced and increased in areas of search-and-rescue. The systems are employed within "Human-Swarm Interaction" where there are multiple robots who coordinate with each other to receive inputs from the teammate (human being). The team of robots is capable of offering instructions on navigation to that human user which indicates that the importance of multiple robots is more than the human user.

The team of multi-human and multi-robots is witnessed for the SAR applications and tasks. The multiple robot controls and assists decision-making of the human beings within a multi-agent setting. An algorithm is witnessed to be proposed for scheduling and sequencing the task to make both humans and also robots work effectively together. [4] argued that multiple humans and a single robot are assumed to be the most common type of robot where for the application of SAR, and the operation of “unmanned aerial vehicles" (UAVs), there are several human beings who collaborate for managing a robot. In case, the robots fail to operate then their incapability will degrade capability of the human beings supervising the multiple robots. A single robot evolves into a distribution agent working in a team of human beings.

Technical challenges in SAR for multi-robot

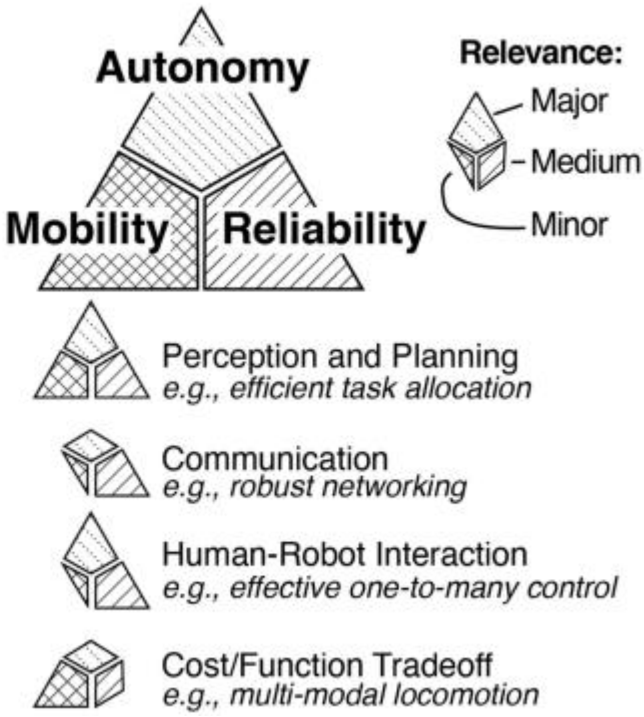


Figure 2: Functionality metrics of MRS
(Source: [5])

Scalability is described as the effect of functionality with the increase in the agent count. Three essential metrics characterise the important functionality of the multi-robot system that are reliability, mobility and also autonomy. [5] opined that some challenging areas within these performance metrics encompass one-to-many control that is directly linked with autonomy and reliability. The multiple robot system (MRS) not only demands a single agent for autonomy yet also system-level requirements which encompass the areas of information sharing and also ability to decide on the constituent robots applicable for performing the individual tasks. The operations on SAR are related to disaster response where constriction of the operation map, development of the "simultaneous localisation and mapping" (SLAM) is considered to be a critical feature for those robots. The SLAM techniques involve certain inherent challenges such as interrobot communication within a dynamic environment.

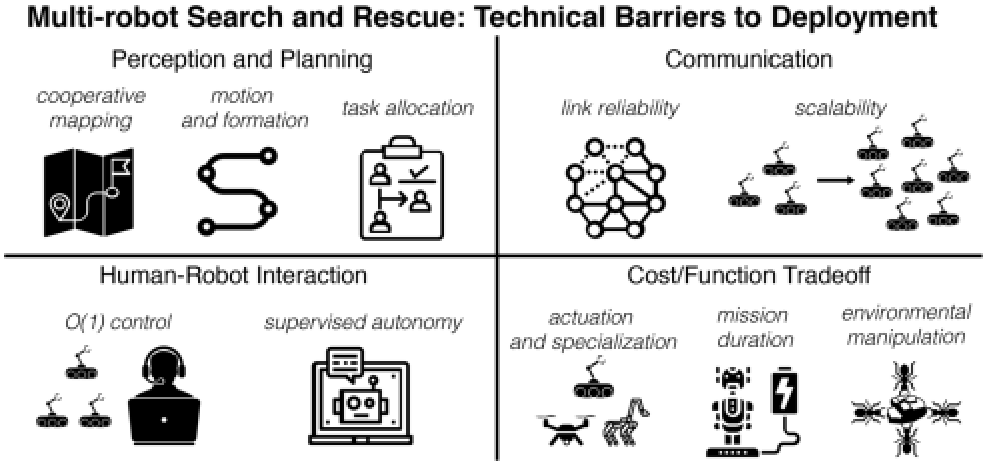


Figure 3: Technical barriers to the deployment of multiple robots in "search and rescue" (Source: [5])

The hardware demonstrations required for the SLAM have practical challenges such as platform cost and availability of testing environment. Another challenge is in the motion planning for offering robot navigation that is assumed to be specific for the utilisation of environments and also for performance demands. [5] argued that the challenge is with communication which requires routing of the state and simultaneously controlling data within the members. Multi-robot control requires centralised and decentralised operations where one hand, a station helps in receiving information followed by computing high level trajectories for those individual agents. The decentralised operation allows the robots to make decisions through usage of their worldview and with the help of the other robots. Difficulties in explicit communication revolve around the existence of tradeoffs between scalability and bandwidth. The agent needs to time-multiplex the transmissions within the slotting system to ensure maintenance of reliability.

In respect of disaster-related operations, there is a requirement for wireless communication that lacks in preexisting infrastructures such as malfunctioning damaged equipment and others. The use of radio-frequency communication needs to be explored as an alternative for improving reliability. [6] mentioned that sight communication in terms of fleets for UAVs ensures difficulties in sightlines due to the presence of dust and also smoke that can curb the signal between "visual", "Infrared radiation" (IR) and also laser systems. Machine learning approaches are effective for communication requirements within the robot teams and will be effective for providing network bandwidth. "Human–Robot Interaction" (HRI) proposes different challenges in relations to teleoperation carried out by ground, aerial robots within a SAR environment. The operators are required to be trained enough to ensure that there are no failures because of the operator's error in the routine and critical setting of the disasters.

There is an existence of tradeoff between functionality, agent count and also price within MRS. Ground robots have been seen to be affordable however, there are some mobility issues with these robots. [7] argued that these robots make use of tread and wheels yet these robots can be hardly deployed within the rescue environments as these robots do to guarantee to navigate to unknown terrain due to their locomotive abilities. Modular robots have been developed for SAR operations where perception-driven autonomy for these robots is effective.

Utilisation of multiple mobile robots for UAVs for aerial surveillance and data gathering

The multiple robots possess a broaden genre in correspondence to UAV where the mobile robots can be used in different activities such as path planning, networking, sensing and others. In order to support these activities, it has been found that there is a coordinated exploration where in the wake of the search operation, the particular robotic configuration tries to increase area information in every phase. [8] opined that in every phase, there is an advancement towards the target that is assumed to be borders of sensor ranges among the known and also unknown space known as edges. The edge is referred to as the frontiers while the algorithm is assumed in the form of frontier-based strategy according to autonomous exploration. It is frontier-based and methodologies on multi-robot exploration are some effective solutions for both single and multi-robot configurations. In case of working with multiple robots, there is a synchronised motion where one robot explores a single direction while others avoid exploring that direction.

The operating area of the robots is static and possesses multiple obstacles which are encountered by robots. However, deterministic technique fails as this technique provides a solution for transforming the physical location of those robots in hazardous conditions. "Hybrid bio-inspired" approaches have been utilised for exploration of the multiple robots where optimisation of multi-robot configuration includes formation and planning of the routes. The optimal solutions revolve around single-objective tasks including shortest path, smoothest route and others. Meta-heuristic as evolutionary algorithms have helped in resolving multiple problems that are useful for robotics. Multi-robot exploration has a restriction where a restricted space has been developed by multiple robots for developing a finite map. [8] argued that multi-robot collaboration has been based on “particle swarm optimisation" (particles constituting the movement of the swarms within the search space) that helps to resolve issues with "multiple odour source location". There is a modification in PSO algorithm that is found to be effective for cooperation techniques with the robots for directing them in the search for finding an odour source.

The search space is witnessed to be divided into different grid cells where positions of each cell are detected by those robots. [9] quipped that robots receive a repulsive force while locating themselves within the cell that is proportional to the positions saved by the cells through the searching phase of the odour plume. Two cognitive elements within PSO have been altered as per impact of the wind on self-cognition and social cognition of the particle for improving the efficiency of the particle while traversing that plume. "Hybrid Stochastic Optimisation" (HSO) algorithm provides cost value across the robot to offer information to the robot followed by instructions from stochastic operators that helps the robot to plan the motion.

Creation of such a finite map is aimed towards multi-robot space exploration where robots have been assigned their roles and computation of the effective action to curb complexities where those trajectories are computed through meta-heuristic techniques. The roles of the multiple robots have been based on searching for individuals and rescue them through UAVs. [10] argued that occupancy map has helped in transforming unknown towards known modes within the cells through upgrading robot position. The data derived from exploration results helps in building the map of the specified area whereas various algorithms help in communication among robots. The common map is made for multiple robots while an individual map is made for every robot.

METHODOLOGY

Machine Learning is used for situational awareness, which is assumed to be an important element for conscious and also intelligent interaction carried out with the world. In order to develop such awareness, “accurate and real-time intelligence data” have been gathered for ensuring timely and actionable information. UAVs have been deployed to evaluate the surroundings around the world and simultaneously collect intelligence through the help of surveillance missions. The maps have been generated through hexagonal mesh, which is equivalent to "5 km square" that is fully connected followed by the removal of the nodes that starts from an outer edge to provide a realistic geographical area for patrol. A sample of around 1000 has been developed and utilised through simulations. The final sample has been found to consist of over 995 regions [11]. The assets for aerial surveillance such as drone and drone bases have been kept followed by placement of the respective bases implemented through two variations such as purely random and near-optimal.

There is an equal number of those drones and the bases whose initial location have been chosen randomly. Autonomy of every drone has been set at around 60 [11]. The bases have been moved apart through a repulsive field. The distance considered to be 100m among the way points makes the corresponding distance to be the total distance that has been traveled as per trip of 6 km. In case the drone’s autonomy has been set at a realistic of around 30 minutes that indicates a time-unit of around 30 seconds followed by flight speed of around $12 km/h$. Each drone has spent an equal time in terms of flying, on stand-by and others implying that one-third of that fleet will be airborne at one time.

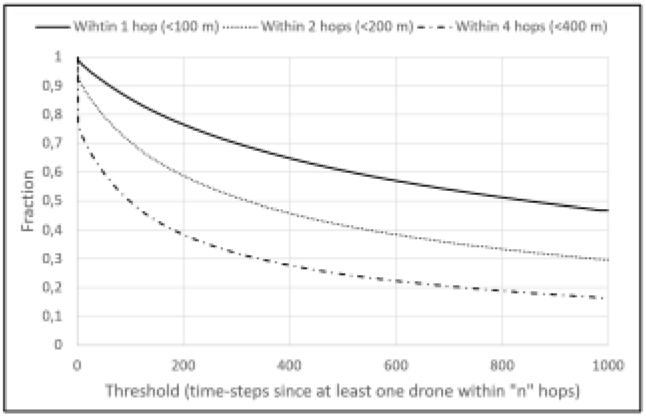


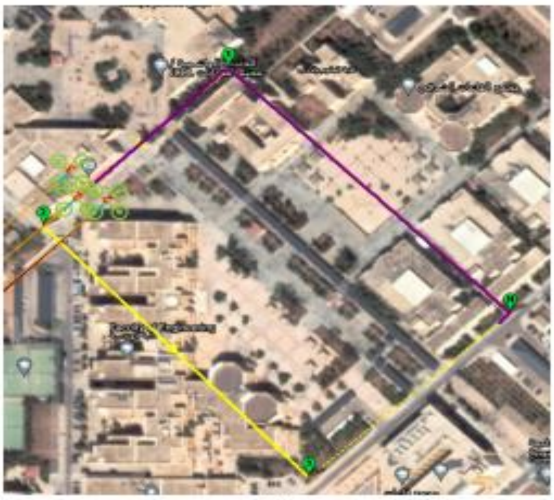
Figure 4: Survival curves as an indication of the fraction nodes within the hexagonal mesh
(Source: [11])

Each drone has been computing a flight plan that is based on significant information (data gathering) obtained from Digital Twin (DT). DT is the virtual replica associated with the physical system. There is a minimisation of information age through continuous observation of locations for schedules. The values have been recorded within the DT. In case 6 drones have been seen to be flying and around 120 nodes at 95% will not be visited which is assumed to be less than a single step ago [11]. The fraction of those "surviving nodes” seems to decrease with the increase in threshold value which is an indication for patrolling the area. Two hundred simulation runs have been seen to be conducted in every region within the estimated sample where every simulation seems to have lasted for around 2000 time-steps that are enough for reaching a steady state.

Findings and Discussion

Findings

Experimental Setting and its results



(a)

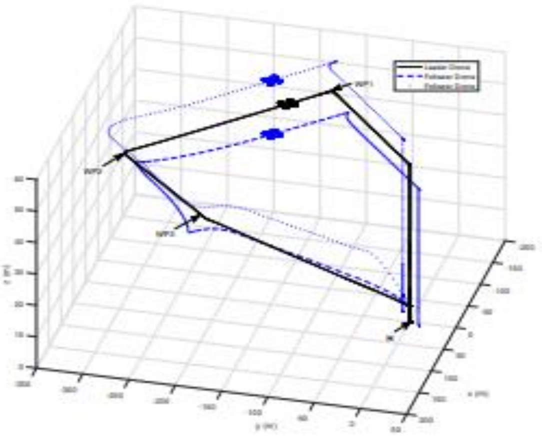


Figure 5: Three-drone mission where one drone is seen to be leading another

(Source: [12])

The "guidance, navigation, and control (GNC) system" has been evaluated through MRS therefore, in this experiment multiple robots are involved. The performance related to the GNC has been analysed based on two varied environments where the first environment is assumed to be an indoor environment encompassing three platforms on robotics while the second environment has been revolving around outdoor involving three drones and also "two-car-like robots". The indoor environment shows that robot platforms containing "motion capture systems" have been able to offer real-time position along with orientation [12]. However, in this section, the performance will be illustrated to further demonstrate the result obtained from a network of drones and multiple teams of ground robots. However, the first scenario has been conducted through three drones out of which one has been seen to be assigned to supervise the others on a path according to the above image.

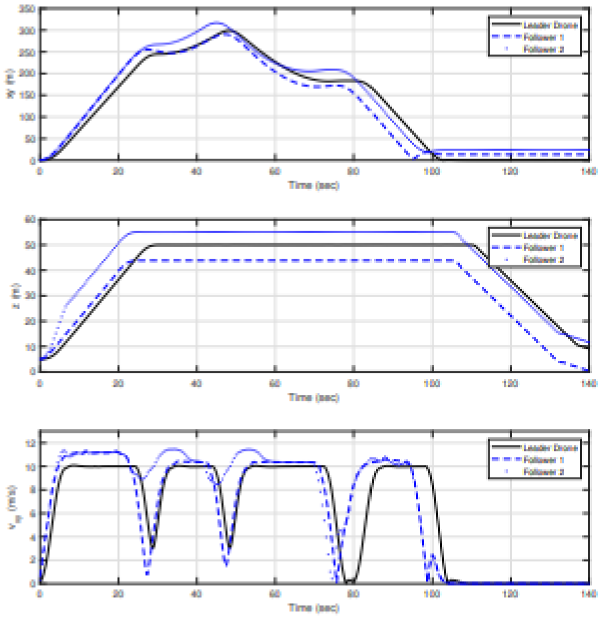


Figure 6: "Position" and" Velocity" of the "three drone mission

(Source: [12])

Three drones have been witnessed to be launched in the same place that has been following the way-points. The three drones have been further seen to have completed the mission because of tasks managed by the multiple robots effectively where the lateral speed of the drones has been around 10 m/s at various heights [12]. There have been no collisions among the drones therefore, absence of collision has led to the maintenance of constant distance. The three drones have been programmed for surveying the area which is around 87,000 m2.

Figure 7: Photograph of different locations by each drone

(Source: [12])

Each drone has to survey a certain portion of the area and take photographs of different locations followed by the involvement of a team of two ground robots who have been assigned to monitor the overall task. Each robot has been instructed to follow a definite path at the same time and the same location (campus).

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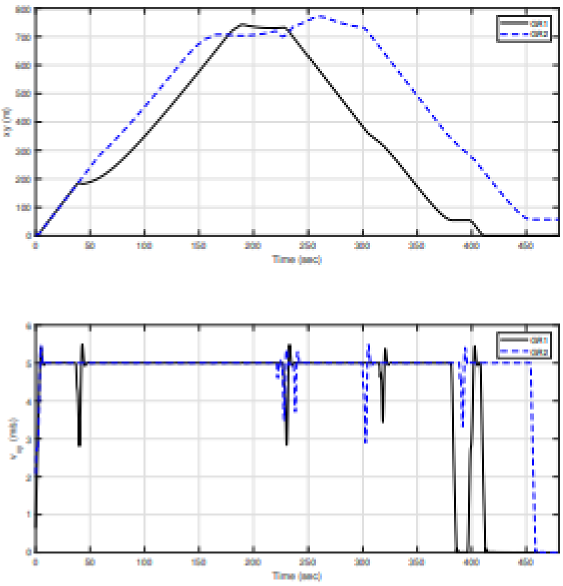

Figure 8: "Positions" and "velocities" of ground robots (Source: [12])

Each robot has been seen to be moving at a speed of around 5 m/s in the path that has been around 1770 m long in case of the first robot and 2390 m in case of the second robot. The first robot has been seen to have completed this task within 390 seconds however, the second robot completed the same task within 490 seconds [12]. The performance of the ground robots is similar to performance of the aerial robots in comparison with a single robot as it would have been difficult for a single robot to manage different paths of the three drones within the campus simultaneously. The single robot would not be able to complete the task within such timing as performed by those multiple robots.

Discussion

Evaluation of "Coverage path planning" (CPP) for single and multiple robots

CPP is assumed to be a process for computing the feasible path that will help a robot to pass in a way to scan and survey the environmental structure. However, CPP can be defined as the path for exploring and searching the space in case of an interesting structure or respect of an environment. CPP techniques include "object reconstruction", "surveillance", "structure painting" and others [13]. The factors that impact the "multi-robot CPP's" performance are task allocation, information sharing, path generation, reaction towards dynamic changes and others. Using a single robot has various disadvantages where either a large structure or a specific broad area may suffer from different drawbacks which include length, energy of the robot, time, along with information quality and quantity. A single robot may not be able to multitask where at the same time, the robot has to map out the location, conduct aerial surveillance and obtain data accordingly. It may happen that a single robot has lost an opportunity of monitoring the process, which is the reason that multiple robots have been more productive for multiple operations.

The approaches involved with Multi-robot CPP have been more useful as there are some additional factors associated with it such as "cooperation type", "robustness of agent failure handling", "task allocation", "robot endurance" and others. In case a robot within the multiple team of robots loses out energy then another robot will come to the forefront to assist the team to fulfill the mission. The important aspect of the multiple robots revolves around generation and also path planning. However, there are some remaining aspects involving communication and task allocation that seem to be critical as these are challenges that have already been discussed above. Communication is considered to be a vital process however; this communication process is dependent on information sharing and also on coordination to conduct collaborative tasks [14]. The "mobile adhoc network" (MANET) has been developed for enhancing wireless communication as well as routing different task messages among multiple robots.

Task Allocation as an evolving problem for multiple robots

Task allocation is about optimisation of several tasks to different robots where this particular problem sometimes becomes a big one in case of handling a large group of robots. Centralised systems are assumed to curb the duplication of the information system and simultaneously check out for the quality of the generalised solutions therefore, maintenance of the connectivity among the central agents and also robots have been difficult in the real-world [14]. Single-task robots have been able to perform a task while multiple-task robots may include several robots for performing multiple tasks. On the other hand, it has been further found that single-robot tasks require a single robot for performing a single task whereas multiple-robot tasks are in demand different robots based on cooperation among those robots for the accomplishment of the main task of SAR, aerial surveillance and others. Therefore, performance of each robot matters the most in multiple-robot tasks and it is difficult to determine capability of each robot within the multiple team for performing a particular task, which makes task allocation problematic.

In addition, other problems have been associated with the task allocation of the multi-robot "multiple traveling repairmen", and others [14]. The main aim of "multiple traveling repairman" has been about determining the tour of every repairer where this repairer has been allocated the task of repairing the problem of the robot within a team for performing the task that has been allocated to the robot. In respect of centralised approaches, there is an intermediate robot that usually collects the information and also allocates the tasks within the team. The main goal is to optimise the overall data. In case the activities related to training and repairing for conducting the SAR and aerial have been performed before on the multiple robots, then these robots will work together cooperatively to fetch positive results.

Capability of multiple robots over a person

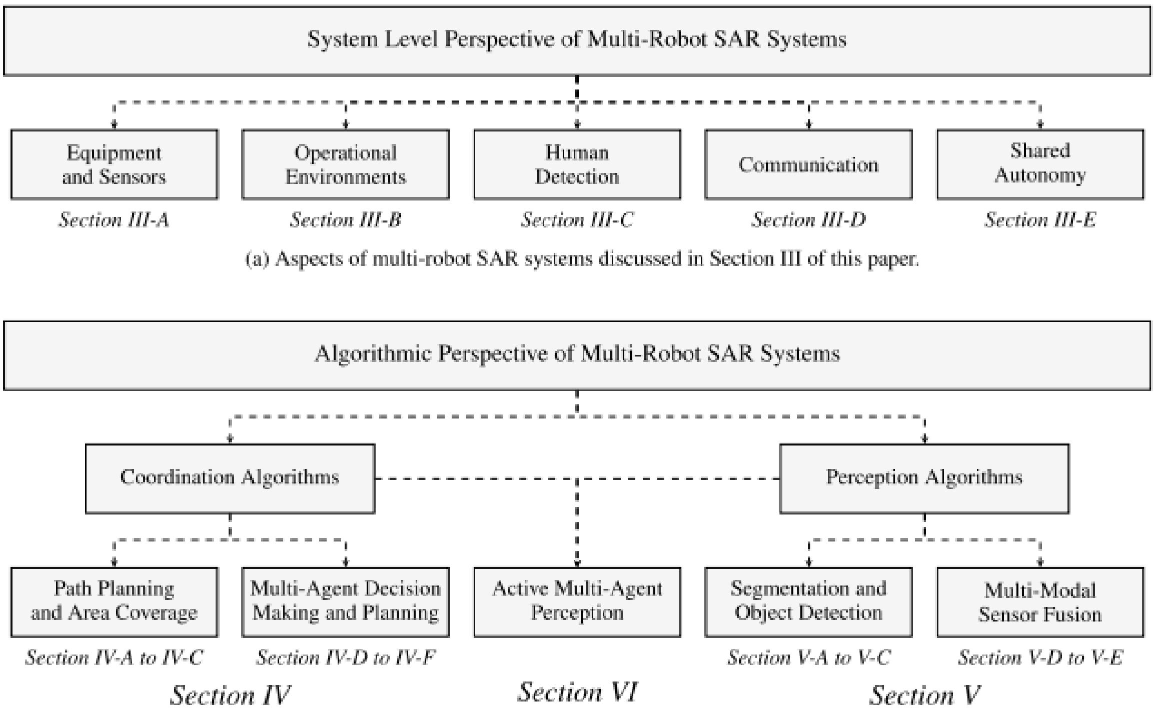

Figure 9: Multiple-robot SAR system from algorithm perspectives
(Source: [15])

SAR operation is about mapping, conducting an assessment, surveillance, and others through developing the communication networks and also searching for the victims. "Multi-robot SAR systems" possess two complementary purposes such as controlling and coordinating algorithms and also use of deep learning models for online perception. There are two levels of perspectives where the system level perspective revolves around use of equipment, sensors, operational environment, human detection, communication and shared economy [15]. The other level of perspectives is algorithm perspectives emphasises on coordination algorithm that involves path planning, and also area coverage, decision-making and planning through multiple-agent. The activities such as "segmentation and object detection" and "multi-modal sensor fusion" have been associated with perception algorithms.

UAV technology has the advantage of handling complex tasks and also missions where the application of UAVs has been increasing. The most challenging aspect of SAR operations is that a crisis can take place at any moment and every place. The success of the use of the application of UAV technology in SAR operations revolves around the time that is required on the part of the first responder to gain awareness about how imminent human life and human life can be in danger [16]. Therefore, in this scenario, human life is falling into danger and multiple robots are considered to help those human lives at risk. UAVs have been capable of increasing rescue mission in the wake of enhancing the efficacy. In order to increase the survival time of the victims, the multiple flying robots can transport the rescue apparatus in an increasing speed than the rescue crew. Thus, a single human and multiple human does not possess the capability to increase efficacy of rescue mission. Teleoperated UAVs provide robotic assistance during emergency management where "ROLFERs" (Robotic Lifeguard For Emergency Rescue) has been navigated and operated to offer emergency services to several humans in the maritime crisis [17]. Pointing out the distressed humans through the help of the "precise point positioning" (PPP) accuracy of "global navigation satellite system" (GNSS) techniques of some portable devices including smartphones.

CONCLUSION

The article has discussed both the operation and technical difficulties encountered while using multiple robots for SAR. However, there is a distinct section to understand the SAR operation carried through UAVs for the purpose of aerial surveillance. A single human or a robot may lose out the capability and energy while handling a complex SAR operation while a multiple robot will use a number of robots in place of another to compensate the energy and the capability within an operation. Both the challenges and the benefits of multiple robots have been discussed to understand its application in the SAR.

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